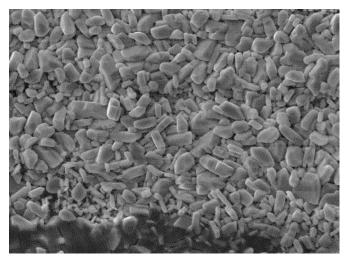


Advanced Lead Based Active Materials for Critical Battery Applications

Tim Ellis RSR Technologies Dallas, TX

Structure Defines Properties: Better Structure = Better Batteries



Typically lead sulfate grows over the life of a lead acid battery limiting performance, i.e. dense faceted orthorhombic crystals



SUPERSOFT-HYCYCLETM stimulates the formation of platelets composed as bundles of $PbSO_4$ nanorods. Performance is increased by >2X



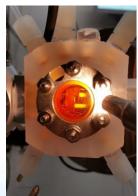




- Argonne National Laboratory
 - Joint Center for Energy Storage Research (JCESR)
 - Argonne Collaborative Center for Energy Storage Science. (ACCESS)
- Real Time analysis of Pb-Acid batteries, an extension of techniques developed for Li ion and other systems
- The APS is one of the worlds premier facilities, the brightest tunable beam with multiple techniques in hand
- CRADA's
 - East Penn Mfg. and RSR Technologies est. Jan 2017 in qualification
 - O US members of the ALABC, results 4th qtr. 2018









Results to Market

- Incorporated in SUPERSOFT-HYCYCLE™ product in product qualification testing
- Presented at "Battery Day" at ANL June 14th, 2017
- Invited to the "BASIC RESEARCH NEEDS WORKSHOP ON NEXT GENERATION FLECTRICAL ENERGY STORAGE" sponsored by the USDoE's Office of Basic Energy Sciences **Battery Workshop**

INVESTIGATING SULFATION IN LEAD ACID **BATTERIES**

RSR Technologies, East Penn Manufacturing, Argonne National Laboratory

APPROACH

Tim Fister, Matthew Weimer, Eric Coleman, Pietro Papa-Lopes, Nenad Markovic (ANL) Matthew Raiford, Tim Ellis (RSR Technologies) Subhas Chalasani, Kevin Smith (East Penn)

MOTIVATION

affecting DCA are:

- Intraplate conductivity - Gassing of O2 and H2

- . Despite 100+ years of use, the energy density of lead acid
- Acceptance (DCA) plays a key role in the energy density and lifetime of batteries, especially during operation at partial state of charge. The major issues
- Dissolution of PbSO, · Models and strategies for
 - the DCA have been inferred from electrochemical testing and post-mortem characterization Argonne has unique canability to

species and morphology

of electrode/electrolyte

species in working cell.

measure changes in

methods.

. Phase II: Adapt these probes to model NAM

. Initial goal: focus on dissolution of PbSO, at the negative Ph electrode Improve

kinetics of PbSO4 with its morphology.

metal electrodes. Develop operando

diffraction, imaging, and spectroscopy

reversibility by connecting growth/dissolution

. Phase I: simplify reaction by starting with lead

METHODS

- Synchrotron-based diffraction and tomography
- In situ (high energy, up to 100 keV)
- Real-time (Intensity = 1010 1013 photons/s) - Spatial resolution (10-1000 nm)



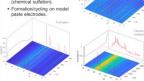
- In situ ICP/MS (part-per-trillion sensitivity) In situ AFM, QCM (atomic scale
- growth/dissolution)
- · World class battery fabrication/testing labs.

EXAMPLE: REAL-TIME X-RAY DIFFRACTION

· Single-shot powder diffraction (~0.5 s resolution) · Easily measure the kinetics of sulfation desulfation



naste electrodes



EXAMPLE: HIGH RESOLUTION TOMOGRAPHY

. Synchrotron-based diffraction and tomography can be used to follow 3D changes in morphology with µm resolution. . CT scans are fast (< 1 min) and use high energy x-rays











EXAMPLE: SURFACE SENSITIVE TECHNIQUES

· Surface diffraction and in situ atomic force microscopy provide atomic scale information on the nucleation and growth of PbSO4 single crystal surfaces.





- . The growth and dissolution of PbSO₄ in lead acid batteries is a multidimensional problem ranging from atomic scale changes at the charged interface to transport
- · Argonne has developed tools capable of measuring sulfation during operation of a lead acid cell to validate and extend existing models based largely on

NEXT STEPS

- . Develop paste electrodes further.
- . Begin analogous studies on the positive electrode material. · Incorporate modeling of crystal growth and continuum pack-level features.





CONCLUSIONS

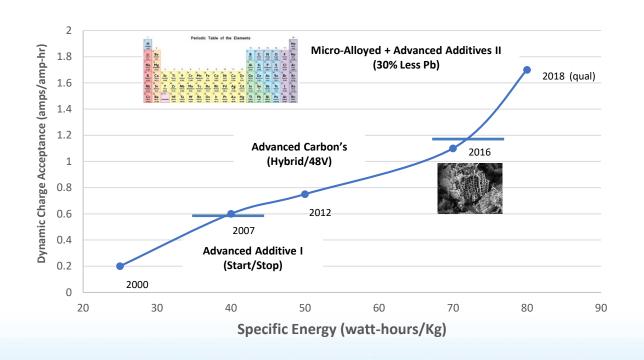








Progress in Performance





CPHRI Lead Battery Pilot Programs

- Advanced Battery Concepts: Workplace and Environmental Manufacturing Emissions Reduction through Green-Seal® Manufacturing Techniques
- Hammond Group Inc.: Improved Charge Acceptance for Group 31 Bus Batteries and Improved Charge Efficiency on Deep Cycle Batteries
- Doe Run: Flubor Hydrometallurgical Process for the Recycling of Pb-Acid Battery Scrap



Lead Based Energy Storage

- Improvements from research programs increase performance allowing significant reduction in lead content and longer cycle life, = Less Lead/Kw-hr
- Cost-effective displacement of fossil fuel based energy sources in transportation, grid storage and behind the meter applications, = Lower energy cost/Kw-hr and Lower emissions/Kw-hr
- Opportunities for further emission reductions associated with lead battery manufacturing and/or recycling, continue to lower the externalities of Lead usage
- True market-ready drop-in replacement with no compatibility issues, safety issues or need for more complex systems (i.e., to manage multiple chemistries).





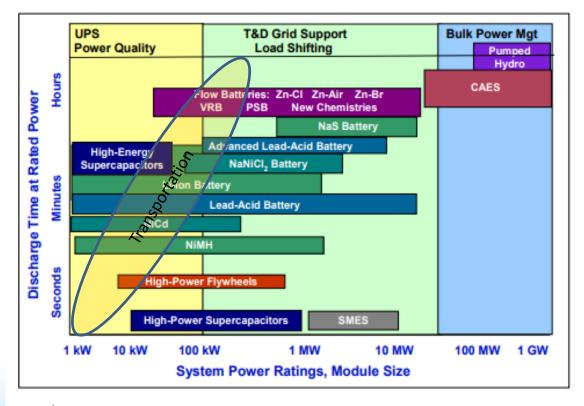
Thank You

USDoE forward looking metrics

- Cost <\$80/kw-hr (acquisition) = cost of hydrocarbon fuel
- Per Cycle cost <<\$0.10/kw-hr per cycle (operational cost)
- Recharge from 20% -> 80% <20 minutes
- Puts rechargeable energy = fossil fuels



One Chemistry for Societies Applications



DOE/EPRI 2013 Electricity Storage Handbook in Collaboration with NRECA



Cost of Ownership Comparison

	STOP-	MICRO	MILD	FULL	PLUG-IN	ELECTRIC
	START	HYBRID	HYBRID	HYBRID	HYBRID	VEHICLE
Idle Elimination	✓	✓	✓	✓	✓	✓
Regenerative Braking		✓	✓	✓	✓	✓
Acceleration Boost			✓	✓	✓	✓
Electric-only drive				✓	✓	✓
Electric motor power			10-20 kWh	30-40 kWh	50 kWh	above 80 kWh
Electric motor power Preferred primary battery	lead acid	lead acid	10-20 kWh Li+	30-40 kWh Li+	50 kWh Li +	above 80 kWh Li+
·	lead acid 20	lead acid 45				
Preferred primary battery			Li+	Li+	Li+	Li+
Preferred primary battery Annual gasoline savings	20	45	Li+ 260	Li+ 300	Li + 450	Li+ 600

^{*}Based on 15,000 miles a year, \$3.00 per gallon of gasoline. Study was of consumer level cars under approximately \$35,000 MSRP.



Advanced Lead Acid Battery Consortium (ALABC)

- International consortium of 77 companies
- Leading development of technology for Pb-Acid
- Leading activities drivetrain development
 - Stop/Start: Gas, Diesel, NGV
 - 12V/48V/200V Mild/Micro hybrid systems
 - Electric supercharging & turboelectric energy recovery
- Partners
 - Ford, Hyundai, USDoE, Valeo, AVL Schrick, AGL Resource, Southern California Gas, Ricardo, UK Technology Strategy Board

The LC SuperHybrid Project

Utilizes advanced lead-carbon batteries along with a belt-driven Integrated Starter Generator and an electric supercharger to increase battery charge and engine efficiency, lower carbon emissions and boost performance in 12V and 48V mild/micro hybrid vehicles.





The Natural Gas Hybrid Vehicle

Combines advanced lead-carbon batteries with a natural gas-powered engine and a factory-built start-stop system in a RAM truck to achieve lower emissions and reduced fuel costs, giving fleet owners a low-cost alternative to conventional trucks.

The ADEPT Project

Applies 48V "intelligent electrification" concepts using advanced lead batteries to deliver full hybrid equivalent fuel economy and performance with lower CO2 emissions at a significantly lower cost.





The Kia Optima T-Hybrid

Offers a 48V micro/mild-hybrid propulsion system featuring advanced lead-carbon batteries similar to the LC SuperHybrid concept and is the first of its kind to be demonstrated in collaboration with a major automaker.

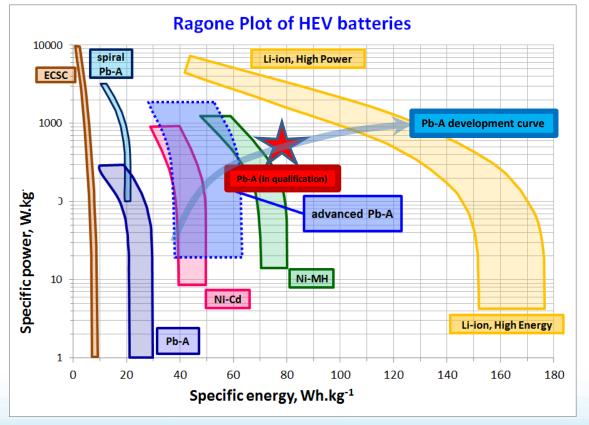
The UltraBattery Civic

Demonstrated that lead-carbon UltraBatteries can out-perform Nickel Metal Hydride batteries in mild hybrids (with start-stop) by running for 160,000 miles in real-world courier duty at varying temperatures with no significant power loss.





Improvement in Pb Utilization in batteries





What do we see?

